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Traffic Flow Pattern Based Approach to Predict Real Driving Emission Test Routes

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Highlights

- This paper focuses on creating driving routes for type approval emission tests.
- A new approach is introduced to getting Real Driving Emission test routes.
- A pre-defining test route strategy provided lower cost emission test and saving of time.

Article Info

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Keywords

Emission test
Real driving emissions
Dijkstra algorithm

Abstract

Due to the poor representation of NEDC emission test, the European Commission put into the force a new procedure, which contains both a laboratory test and a real word driving test. In this new test procedure, even though WLTC replaces NEDC, it is required to test the vehicle under real traffic conditions, which contains urban, rural and highway segments. Due to the new emission regulation, considerable number of academic work focus on the creation of RDE (Real Driving Emission) routes and RDE tests. In this study, it is introduced a new methodology for creating potential RDE routes. The routes, created in MATLAB code by using Istanbul road data containing a half an hour average trip records were used to predict a probable RDE test road. This model creates a number of RDE routes starting from defined coordinates and then analyses all alternative routes with respect to traffic flow rate and RDE boundary conditions identified by the European Commission. The routes obtained using the methodology developed are tested in real life conditions and evaluated according to actual existing traffic conditions. The agreement between the results of the method and the results of the actual driving test is limited in urban road section. However, for rural and highway road sections, there is a significant agreement between the predictions and actual test results.

1. INTRODUCTION

Global and local emissions from the combustion of fossil-based fuels cause air pollution and contribute to global warming [1, 2]. CO_2, one of the most important global emissions, increases global warming by creating a greenhouse gas effect [3]. Global CO_2 emissions, which were 0 in the 1850s, reached 32,500 million cubic meters in 2010 [4]. The reason for about a quarter of this situation is the transportation system [5]. Fuel consumption, which has increased by 34% from 1990 to 2017 in the transportation system, has also led to an increase in CO_2 emissions in a direct proportion [6].

Other locally based emissions from road vehicles are HC (Hydro Carbon), CO (Carbon Monoxide), NO_x (Nitrogen Oxide) and PM (Particulate Matter). Among these emissions, HC and CO emerge as a result of incomplete combustion and occur more in gasoline vehicles [7]. Both gases are toxic and have a significant impact on human health [8]. NOx and PM emissions are important local emissions caused by diesel fuelled vehicles [9]. These pollutants are also very dangerous in terms of human health and the environment, and the share of the transport system in these emissions is at the highest level with 22% [8, 10]. In addition, Fine Particles, to which NO_x and PM emissions contribute significantly, can be absorbed up to the human lungs by the respiratory tract [10, 11].

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Since Rio de Janeiro Environment declaration in 1992, European Commission forces exhaust emission regulation for new produced vehicles. To determine whether the vehicle satisfy the regulation limits or not, an artificial driving cycle was created named New European Driving Cycle (NEDC). While this cycle is accepted by most countries including European ones, some countries such as US and Japan define their own cycle to test vehicle emissions [12, 13]. Because the new emission regulation come into the force, vehicle manufacturers had to introduce new technologies with after-treatment systems to reduce engine-out emissions in order to satisfy regulation limits [14].

However, some academic studies done in China, India, Mexico and Istanbul shows that this artificial driving cycles does not represent the real time emissions [15 – 18]. This discrepancy between both types of cycles is due to the differences in the instantaneous values of vehicles' speeds and accelerations/decelerations. By this way, some new driving cycles depends on regional traffic conditions are created. Even though all these studies are only academic level, these researches light to new emission regulation. With this new regulation which is called EURO 6d, the older NEDC laboratory cycle replace with more dynamic cycle called Worldwide Harmonized Light – Duty Test Cycle (WLTC) and new test procedure about real driving condition come into the force [19]. This real driving cycle must satisfy some boundary condition about speed, distance, elevation and time limits. These limits are given in Table 1 [20 – 22].

Table 1. *RDE Regulation emission limits*

Properties	Units	Urban	Rural	Highway
Speed	km/h	$V \leq 60$	$60 < V < 90$	$90 \leq V$
Distance	% of the total	29 - 44	33 ± 10	33 ± 10
Minimum distance	km	16	16	16
Maximum speed	km/h	60	90	145
Total test time	min	Between 90 and 120		
Elevation difference	m	100 m between start and end point		

As seen in Table 1, RDE tests include some boundary conditions as speed limits and distance limits. According to the regulation, emission tests can be carried out on any route that meets these limits. However, it is very difficult to create such a route and maintain the route in terms of testability. In this study, it is introduced a new methodology to create appropriate Real Driving Emission (RDE) test route by using old road traffic flow rate and road map provided by BASARSOFT Company. Although the instantaneous traffic flow varies, it may be possible to generate possible RDE test routes using traffic history data. The aim of this study is to present a methodology that creates an RDE test route for Istanbul, Turkey's largest city and one of the world's largest metropolises.

2. LITERATURE REVIEW

Local and global emissions caused by road vehicles in real traffic conditions or urban traffic conditions is an area where researchers have been working for many years. In many studies, it has been revealed that the actual emissions are higher than the values determined in the laboratory [23 – 26]. In some studies, besides this difference, real driving cycle creation methodologies have been introduced [15 – 18, 27]. The first of these methodologies is the method of selecting micro-trips from multiple GPS tests [16, 28 – 30]. According to this method, a test cycle is created by randomly selecting micro trips to provide acceleration/deceleration frequencies and average values (speed, stop duration, acceleration/deceleration time etc.) of all GPS data. Another method of generating cycles is to use instantaneous speed trips, and in an example study, using thousands of speed data collected in Istanbul traffic, instant speed trips were blended and a test cycle reflecting the average traffic behaviour of all Istanbul was obtained [18].

Creating the driving cycle is also an important issue apart from the emission tests of passenger and light commercial vehicles. For example, in some studies in the literature, driving cycles have been created to determine the performance and emissions of heavy commercial vehicles and city buses [31 – 35]. Apart from these, cycle generation methodologies are also used to examine the performance and emissions of hybrid electric vehicles, which is an important research topic today [36 – 41].

The cycles created in most of these studies mentioned are arranged for testing in the laboratory. Our study, on the other hand, includes RDE route methodology suitable for the regulation tests determined for passenger and light commercial vehicles. The difference from the other examples of this study is that instead of creating a city cycle, it creates emission test routes that take twice as long as the city cycle (based on the WLTC cycle), including the effect of variable traffic conditions and road slopes.

3. METHODOLOGY

The route(s) to be selected in order to perform RDE test will be obtained with this new methodology. In this methodology, possible RDE route(s) determined using old traffic flow data and road map information. Then the speed distribution of the determined route(s) is/are extracted with half an hour average speed data. In this way, by looking at the speed distributions in Urban, Rural and Highway segment lengths and ratios could be calculated and decided whether the route is suitable for RDE test or not. An example of the road map and traffic activity data used in this methodology are given in Figure 1 and Table 2 respectively.

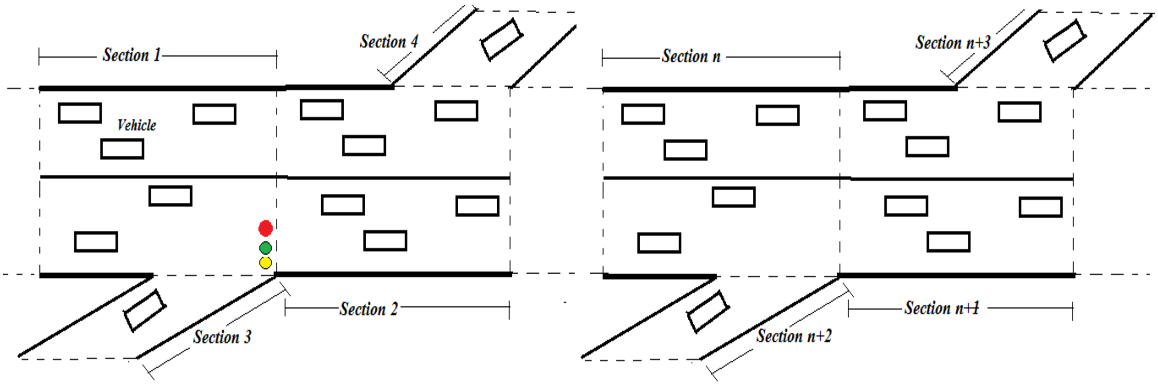

Figure 1. *An example of road traffic data and road segments*

Table 2. *An example of half hour based BASARSOFT road traffic activity*

Sections	0:00 – 0:30		0:30 – 01:00		…		23:30 – 0:00	
	N	V_{mean}	N	V_{mean}	N	V_{mean}	N	V_{mean}
Section 1	N_{1_0}	V_{1_0}	N_{1_30}	V_{1_30}	…	…	N_{1_1410}	V_{1_1410}
Section 2	N_{2_0}	V_{2_0}	N_{2_30}	V_{2_30}	…	…	N_{2_1410}	V_{2_1410}
Section 3	N_{3_0}	V_{3_0}	N_{3_30}	V_{3_30}	…	…	N_{3_1410}	V_{3_1410}
…	…	…	…	…	…	…	…	…
Section n+1	N_{n+1_0}	V_{n+1_0}	N_{n+1_30}	V_{n+1_30}	…	…	N_{n+1_1410}	V_{n+1_1410}
Section n+2	N_{n+2_0}	V_{n+2_0}	N_{n+2_30}	V_{n+2_30}	…	…	N_{n+2_1410}	V_{n+2_1410}
Section n+3	N_{n+3_0}	V_{n+3_0}	N_{n+3_30}	V_{n+3_30}	…	…	N_{n+3_1410}	V_{n+3_1410}

These sections given in Figure 1 are small road segments that are separated by traffic signs, road connection points, intersections or traffic lights. In Table 2, the average speeds (V_{mean}) and the total vehicle number (N) in each half an hour period of sample sections given in Figure 1 are symbolized. These average speed data are used to calculate the flow rates and estimated traveling times of the possible RDE route(s) detected by our suggested methodology.

In this methodology, the route(s) is created according to searching method like as Dijkstra Algorithm, which is most frequently used in navigation systems, tries to find minimum distance or alternative routes with the least cruise time between two points [42]. But in our study we use the searching method to create the longest distance between two connection points (contrary to Dijkstra Algorithm) and to find the route(s) which meet the RDE boundary conditions defined by the European Commission. A sample node and connection path notations of the Dijkstra Algorithm is given in Figure 2.

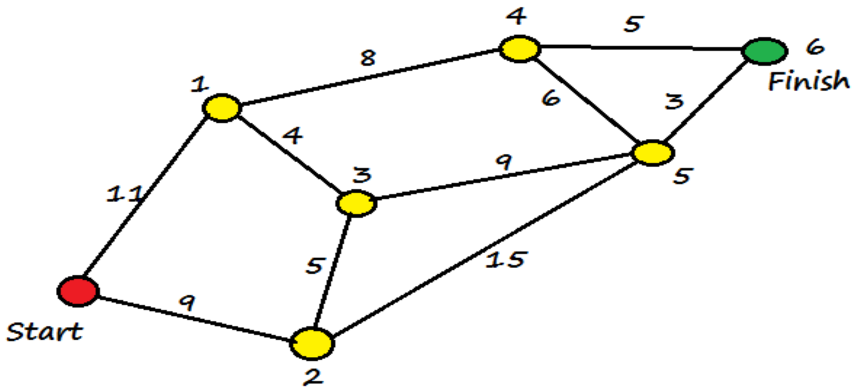

Figure 2. *An example node and connection path*

According to Dijkstra Algorithm, each point on the road is visited to go up to the finish point and the shortest distance, which comes to the same point, is selected. For example, there are two alternative paths from the start point to the point 3. Paths are Start-2-3 and Start-1-3. Since the shorter of these two routes is Start-2-3, the other possibility is ignored and to go to the other points through point 3, the Start-2-3 path is used. By selecting the shortest paths at each step, the Dijkstra Algorithm reduces the size of the path matrix and quickly finds the shortest distance. But in our suggested model, because the final point is not known, the problem is different from that of navigation systems. In our study, the finish of route could be any point on the map, but the route(s) between the start and endpoints must meet the RDE boundary conditions. For this reason, our algorithm, by finding the longest distance instead of the shortest, both increases the urban circulation and tries to achieve the minimum required driving time. The schematic representation of our searching algorithm is given in Figure 3.

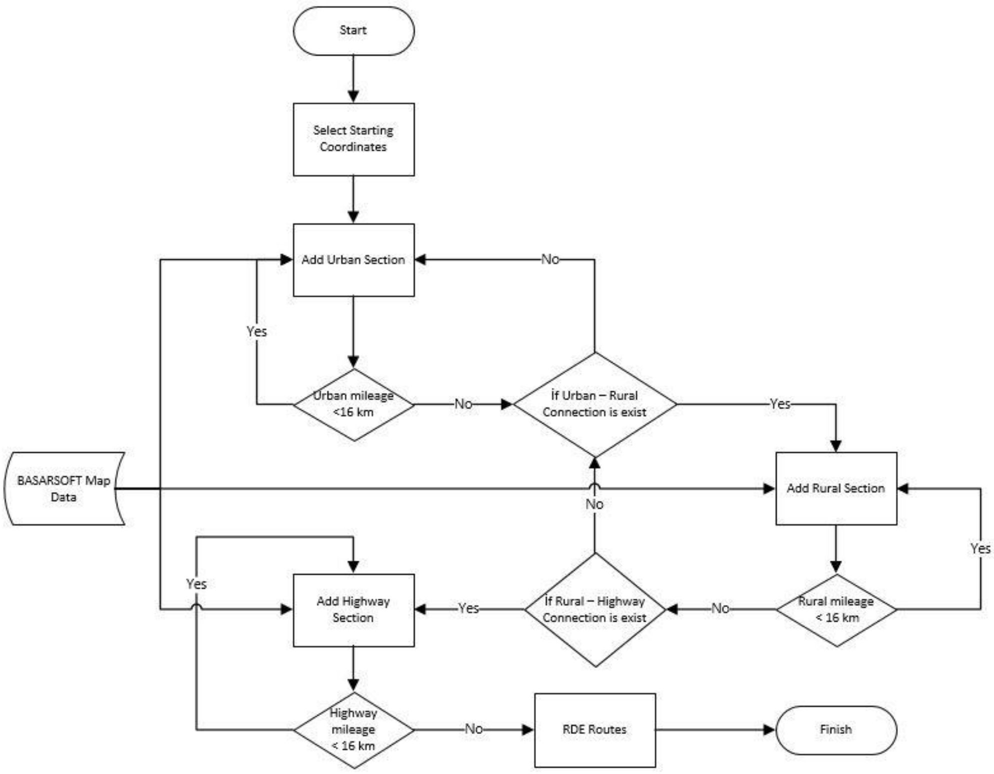

Figure 3. *The flowchart to create of a RDE (Real Driving Emission) test route*

In Figure 3, the flowchart of the model, generates route(s) according to the RDE boundary conditions determined by the European Commission is given. This model was established in MATLAB software and consists of three basic parts. In the first part of the model, road segments are grouped into three classes as Urban, Rural and Highway according to speed limits obtained from traffic data. In the second part of the model, starting from the selected coordinates as shown in Figure 3, Urban, Rural and Highway road segments are created respectively. In this section, according to the logic of the Dijkstra Algorithm, small road segments are added to each other and the whole route is tired had to be obtained. The main condition here is that each road section is at least 16 km long and remains within the distance rates given in the RDE regulation. Therefore, it is checked whether the RDE boundary conditions are met at each step of the algorithm. In each controlled step, when the length of a road section (Urban or Rural) reaches at least 16 km, it is continued to move to the next road section. However, since the Rural and Highway road segments may also contain some urban road parts, only the road speed limits are not sufficient. Moreover, the traffic situation that may occur within the Rural or Highway road section during the real driving causes some parts of these roads to act as urban. Therefore, the third part of the model is used to estimate possible traffic conditions by using half - hour traffic flow data.

In the third part of the model, the average speed distributions of the routes are created in 90 – 120 minutes time frames for a selected day of the week. Then, from a specified starting moment (t_0 = 0, 30, 60…1410) mean segment time (Δt) is calculated using the average speed and length of segments along the route. This calculation continues until the total Δt reaches 30 minutes. After the 30 minutes have been reached, the average speeds of the next segments are selected from the next half - hour period column until the total Δt reaches 60 minutes. This calculation continues until the end of the route or the total cruise time reaches 120 minutes. As a result, some of the routes obtained in the model are eliminated due to insufficient road length, some due to the road ratio distribution that does not comply with the RDE regulations, and some due to insufficient or too long driving times. In most of the remaining routes, it is anticipated that RDE emission tests may be appropriate only on some days of the week and in some time-periods.

4. RESULTS

In this study, it has been investigated whether a sample route obtained with the developed new methodology is suitable for the RDE emission test or not. Urban, Rural, and highway distributions of the selected route were examined according to starting times of 10:00 am, 11:00 am, 12:00 am and 13:00 pm on Wednesdays. In Figure 4, selected for this study, are given Google Earth images and altitude change of a sample RDE route is given. In addition, the characteristics of the sample RDE route at different starting times are given in Table 3.

Figure 4. *Sample RDE route with urban, rural and highway road sections*

Table 3. *Characteristics of the sample RDE route at different starting time*

Starting Time	Urban	Rural	Highway	Driving Time	Comment
10:00 am	46.78 km 63.3 %	25.87 km 35 %	1.27 km 1.7 %	91 min	Heavy traffic on highway cause to longer urban and shorter highway than desired (Fail)
11:00 am	45.58 km 61.6 %	27.35 km 37 %	0.99 km 1.4 %	86 min	Heavy traffic on highway cause to longer urban and shorter highway than desired (Fail)
12:00 am	25.68 km 34.7 %	28.39 km 38.4 %	19.85 km 26.9 %	79 min	Satisfy the boundary condition (Pass)
13:00 pm	25.96 km 35.1 %	28.11 km 38 %	19.85 km 26.9 %	78 min	Satisfy the boundary condition (Pass)

As can be seen in Table 3, the desired Urban, Rural, or Highway ratios (look Table 1) cannot be obtained at all times since different traffic conditions occur in different time periods on the same RDE route. However, there are also appropriate time periods for emission tests of the same sample route. In Figure 5, the average speed distributions, calculated by the model for different four - time zones of the sample route are given.

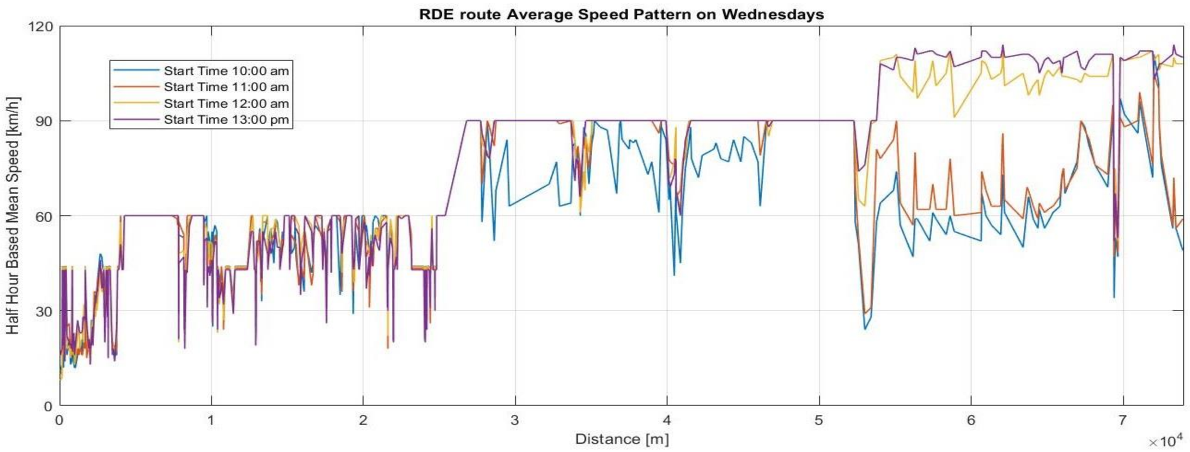

Figure 5. *Average speed changes along the selected RDE route on Wednesday at different times*

As can be seen in Figure 5, possible traffic on the highway sections of the route at 10:00 am and 11:00 am causes to increases Urban and Rural road segments but decreases one on the Highway road segments. However, at the start times of 12:00 am and 13:00 pm, it is observed that the entire route is in accordance with the desired speed limits and segment ratios. The OBD test's distance-dependent speed change and old traffic data on the sample RDE route are given in Figure 6. This OBD test is performed at 12:00 am on Wednesday and the model average speed belongs to the same time-period.

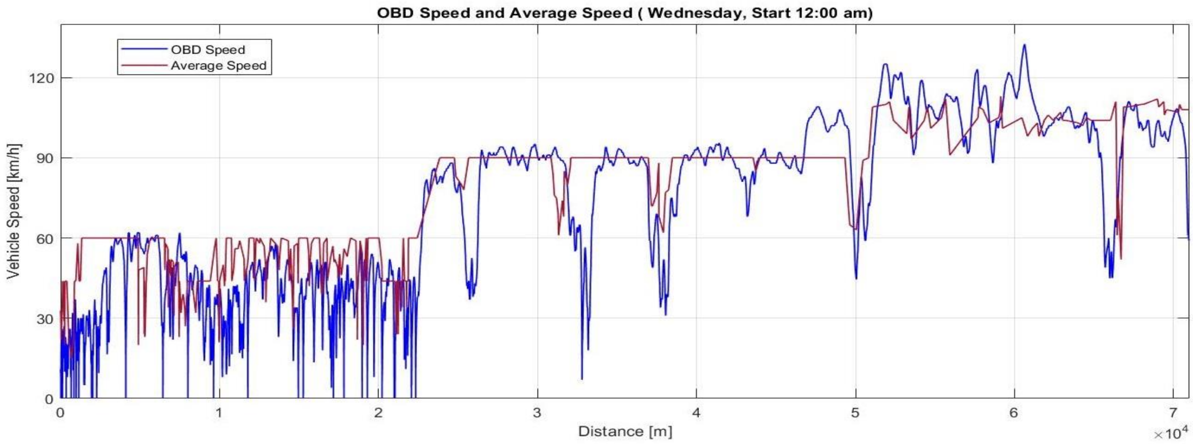

Figure 6. *Average speed and real time speed change on defined RDE route on Wednesday at 12:00 am*

As seen in Figure 6, instantaneous and average speed changes according to the distance are proportional to each other. Although the constant speed and acceleration trends during instantaneous driving in the urban road region are not similar to the average speed distribution, the speed changes highly overlap in the rural and highway segments.

5. CONCLUSION

This study describes a new methodology that can be used to generate suitable Real Driving Emissions (RDE) test routes for vehicles according to EURO 6d and later emission regulations. The generation of possible routes before on-road test measurements can lead to time and cost advantages.

The agreement between the results of the method and the results of the actual driving test is limited in urban road section. However, for rural and highway road sections, there is a significant agreement between the predictions and actual test results. On the other hand, there are some cases to be considered for an RDE test that will be performed using the outputs of this methodology. These cases are as follows:

- There is no objection to start the test 15 minutes before or after defined times by this model. However, testing should be started at the recommended time as much as possible.

- Due to the restriction of maximum speed limits in the proposed method, these limits (maximum speeds of Urban, Rural and Highway) should also be observed during the driving of the tested vehicle.

- While connecting from the rural road part to the highway road part, congestions that may occur during the box office passes will decrease the driving speeds. Therefore, it may be correct to drive according to highway conditions in the last few km of the rural road section.

- Nevertheless, since the outputs of the proposed method are based on old average speed data, the current flow rates of the route must be checked from the navigation before starting the actual driving test.

The suggestion for the future study is that updating the traffic flow history data continuously due to the reasons such as road maintenance works and road route change. Although this method determines possible test routes and test times, the instant traffic situation (traffic accident, traffic control, etc.) should be checked before the test.

While this study facilitates the pre-establishment of possible RDE test routes, it also contains some difficulties and limitations. The most important of these challenges is the need for map data and traffic flow data to create an RDE route. In order to obtain these data, an agreement should be reached with the relevant organizations. On the other hand, even researchers have the necessary data, variable traffic behavior is a threat to the continuity of the probable RDE route. Traffic behaviour varies by time of the year and day-to-day variations are also possible. These random variations in the road data collected influence RDE route creation.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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